SWALES AEROSPACE

FEMCI Workshop

at GSFC

18 May2000

Analysis of Thermally Induced Jitter of the HST Solar Array 3

by Bill Haile

SWALES AEROSPACE

INTRODUCTION

- SA3 will be placed on the Hubble Space Telescope in the next servicing mission to replace the existing SA2
- SA3 is stiff and electrically efficient and will be used to upgrade the HST for astronaut handling and to reduce the on-orbit jitter
- Because the HST is so quiet (jitter < 7 milli-arc-sec, rms) the new solar array must also be quiet
- There is concern about thermally induced motion of the solar array which is being attacked by finite element analysis and by test
- Since test data is incomplete at this time, only the analysis is discussed here

SWALES AEROSPACE

Solar Array 3

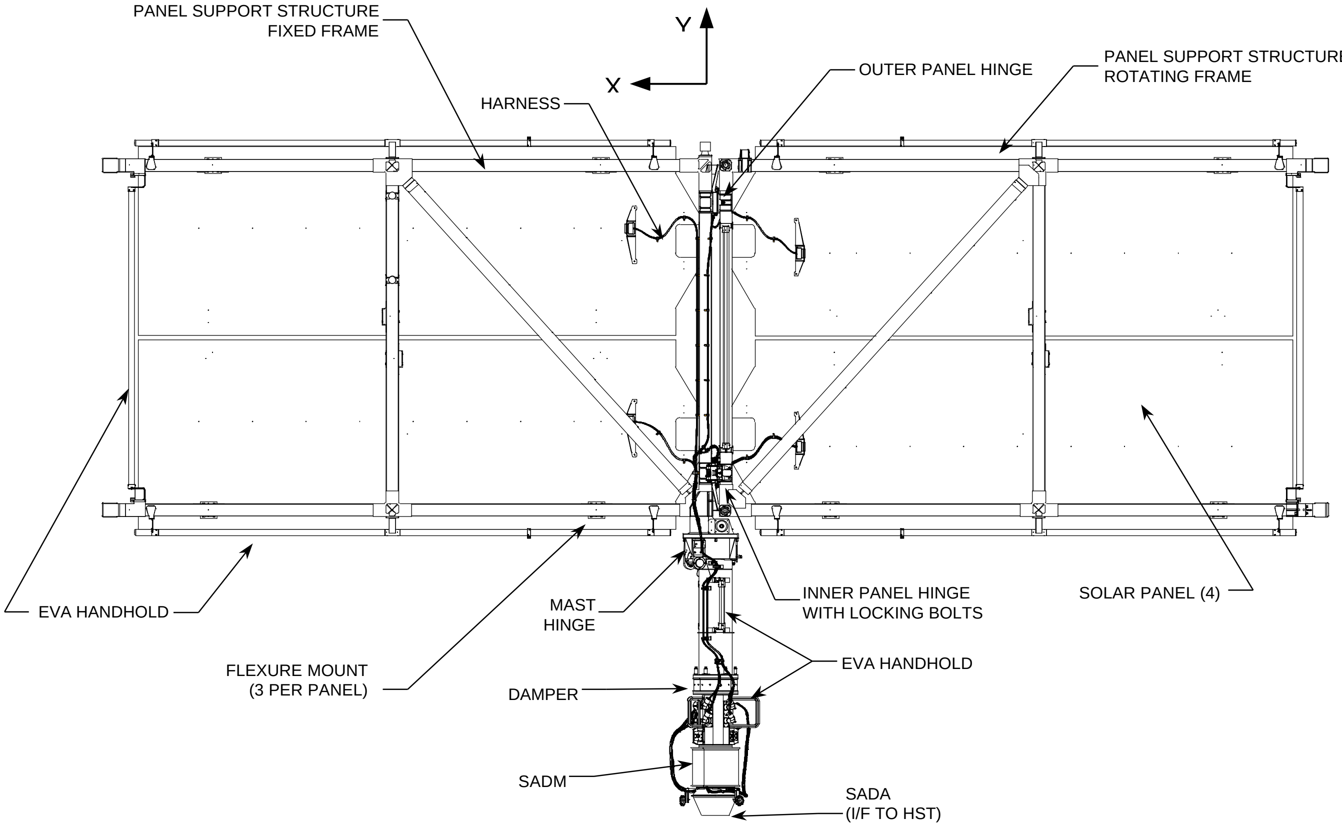
- The new solar array has G/E honeycomb panels mounted on three flexures that are located to minimize motion of the center of mass when thermally deformed
- It includes a damping device in the mast
- Dynamic properties:

Weight 660 lb per wing

Nat. Freq. (Hz)	Damp. (%)	Modal Effective Weight (% of Total at the HST I/F)					
		Fx	Fy	Fz	Mx	My	Mz
0.88	1.15	0.1	0	0	0	99.9	0
1.17	1.81	30.5	0	0	0	0	93.0
1.50	2.25	0	0	61.0	97.0	0	0
5.40	0.16	0	0	3.6	0.2	0	0
6.51	0.16	1.0	0	0	0	0	0.1
6.72	0.89	47.4	0	0	0	0	6.5
8.06	0.46	0	0	7.1	1.5	0	0
13.60	0.52	0	17.9	1.9	0.3	0	0

SWALES AEROSPACE

The Deployed SA3



SWALES AEROSPACE

Thermal Jitter

- Thermal jitter is the low frequency oscillation of a structure due to a rapid change in temperature

  As the structure deforms, the moving mass may cause vibration of the mode shapes which shake the line-of-sight and interact with the s/c control system

- Rapid temperature changes occur in LEO twice an orbit when the SA enters sunlight and when it enters the Earth's shadow

- The specification for jitter is <0.002 Nm torque imparted from the SA to the HST

- Thermal *creak* and *pop* are the sudden release of strain energy due to thermal deformation and are separate topics not discussed here

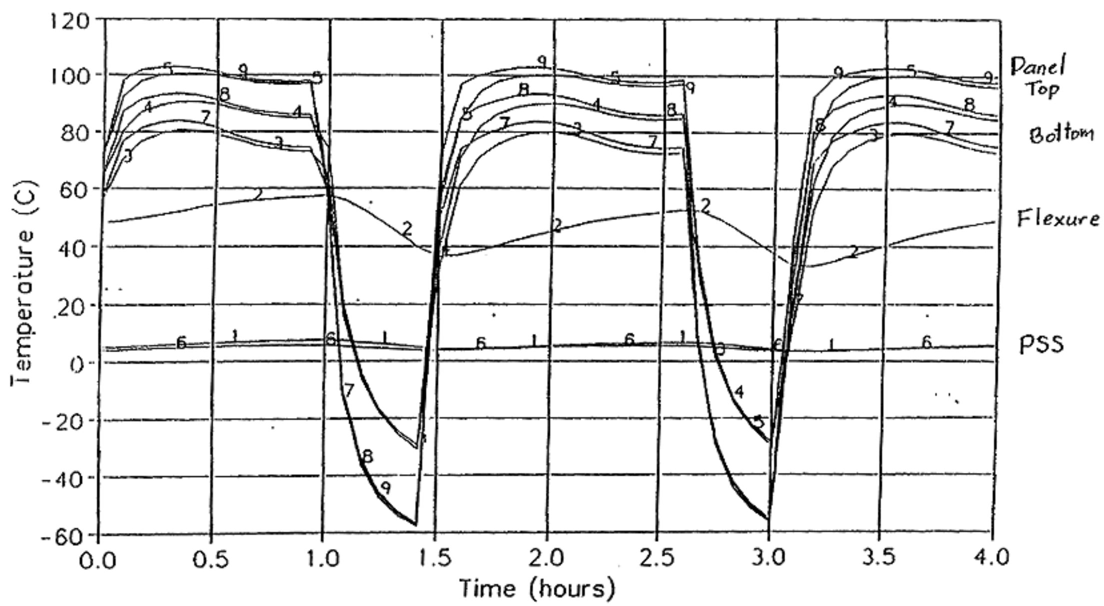
Analysis of Thermal Jitter (1 of 3)

- For SA3, a detailed FEM has been assembled that includes a mass matrix [m] and a stiffness matrix [k] which are used in the equation of motion,

$$[m][\ddot{u}(t)] + [C][\dot{u}(t)] + [k][u(t)] = [f(t)]$$

- A thermal model has also been assembled to predict the changing temperature field

For the thermal transient, temperatures were generated in 0.1 sec steps
The 8 second penumbra effect is critical and is included



SWALES AEROSPACE

Analysis of Thermal Jitter (2 of 3)

- The temperature field is mapped onto the FEM and applied at each time point to calculate the static displacements $[u_T(t)]$
- This same displacement field can be produced by application of a set of static forces found by

  $$[f_T(t)] = [k][u_T(t)]$$

  These forces are self balancing and in static equilibrium at all time points
- The FEM is reduced to Craig-Bampton form by using boundary node functions (constraint modes) [B] and fixed boundary normal modes (constrained modes) [ϕ] by the transformation equation,

  $[u] = [B, \phi]\begin{bmatrix}\bar{u}\\ q\end{bmatrix}$ — $\bar{u}$ is the vector of 6 boundary d-o-f at the HST interface; q is the vector of normal mode generalized displ.

- The C-B modes transform the equation of motion into,

$$[B, \phi]^T[m]\,[B, \phi]\begin{bmatrix}\ddot{\bar{u}}\\ \ddot{q}\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & 2\varsigma\omega_0\end{bmatrix}\begin{bmatrix}\dot{\bar{u}}\\ \dot{q}\end{bmatrix} + \begin{bmatrix}0 & 0\\ 0 & \omega_0^2\end{bmatrix}\begin{bmatrix}\bar{u}\\ q\end{bmatrix} = [B, \phi]^T[f_T(t)]$$

where ς is the normal mode damping ratio, and ω_0 is the nat. frequency (rad/sec)

SWALES AEROSPACE

Analysis of Thermal Jitter (3 of 3)

- This dynamic equation replaces the previous static one and allows the modes to react to the thermal forces $f_T(t)$

  Include lots of modes to allow for the complete thermal distortion of the structure.
  For SA3, modes to 50 Hz were necessary.

- The complete gen. displ. will include high frequency terms as well as the slowly changing quasi-static terms. Assuming that the HST Pointing Control System can correct for quasi-static drift, the displacement that causes jitter is

  $$[q(t)]_{JITTER} = [q(t)] - [\omega_0^2]^{-1}[B, \phi]^T[f_T(t)]$$

  and, because the thermal forces are in equilibrium,

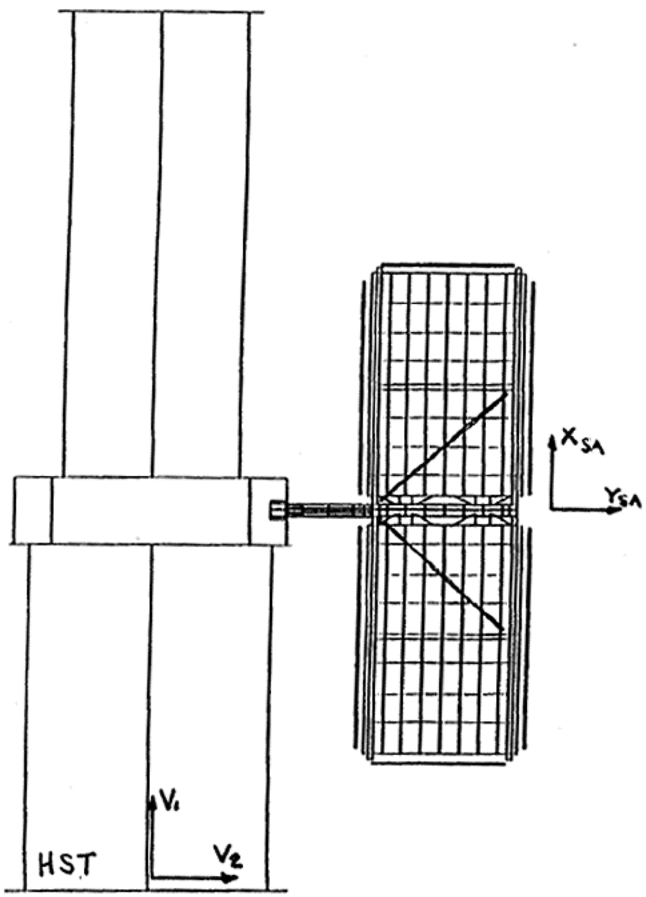
  $$[B]^T[f_T(t)] = 0$$

- Open loop interface forces and moments (or generalized forces) are computed as time functions at the HST interface point and provided to the Pointing Control System as disturbances for closed loop analysis

  I/F forces are exact
  Closed loop simulation includes the quasi-static terms

SWALES AEROSPACE

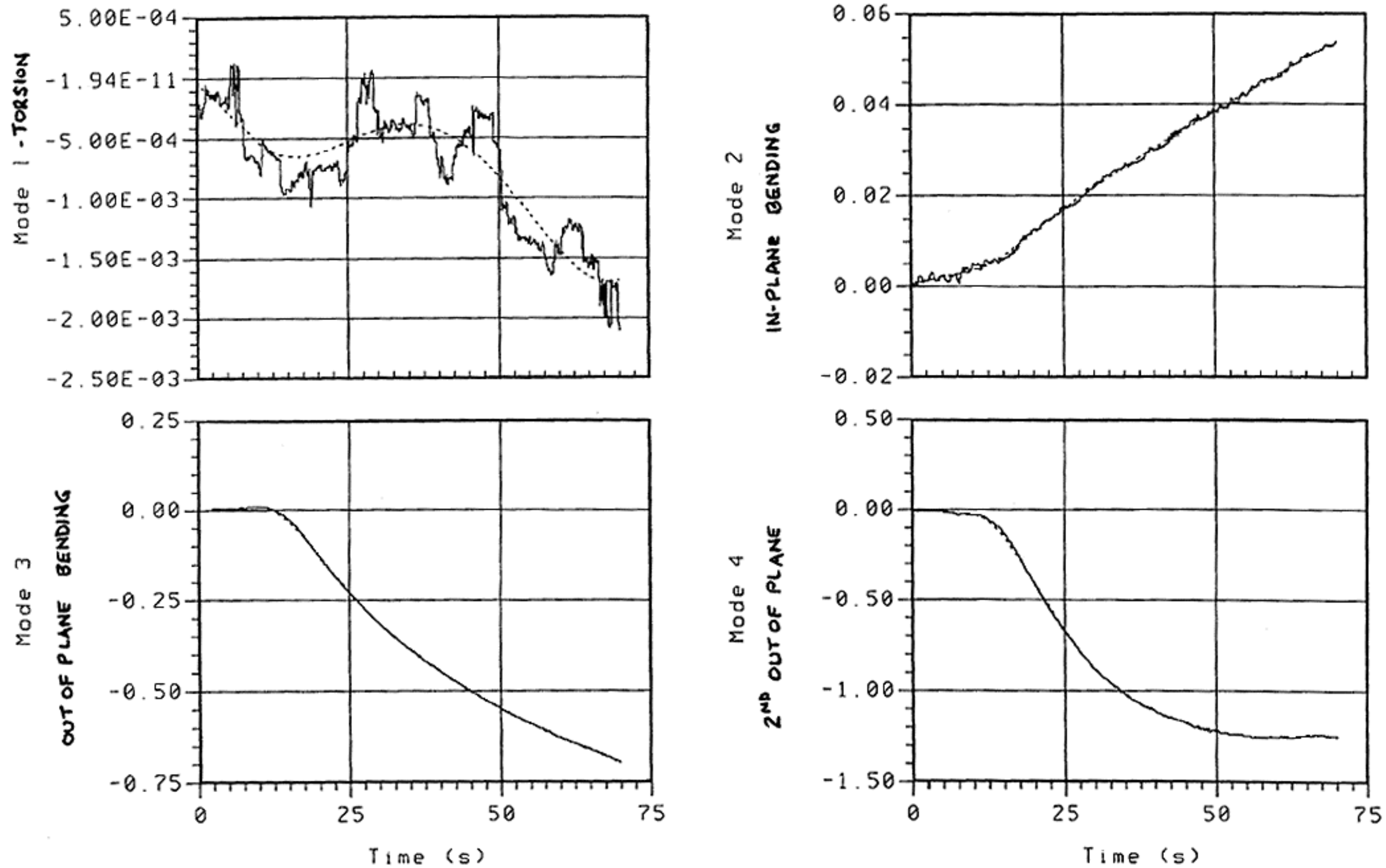
The Thermal Model



- 4x8 grid on each panel
- 8 segments on each beam
- 995 thermal nodes are mapped into 11,432 grids in the finite element model
- Gradients thru the panels, PSS beams, mast and handrails are included

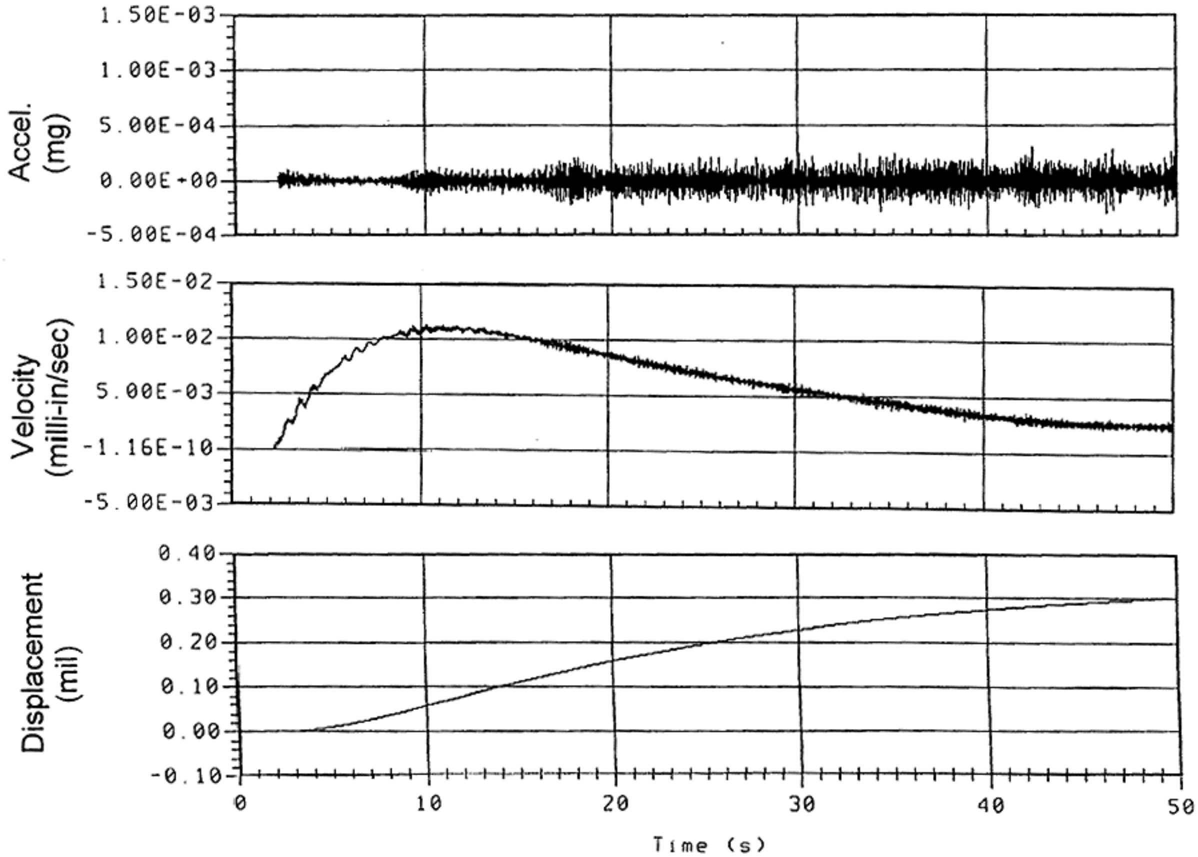
SWALES AEROSPACE

Sample of Results - The Generalized Forces



SWALES AEROSPACE

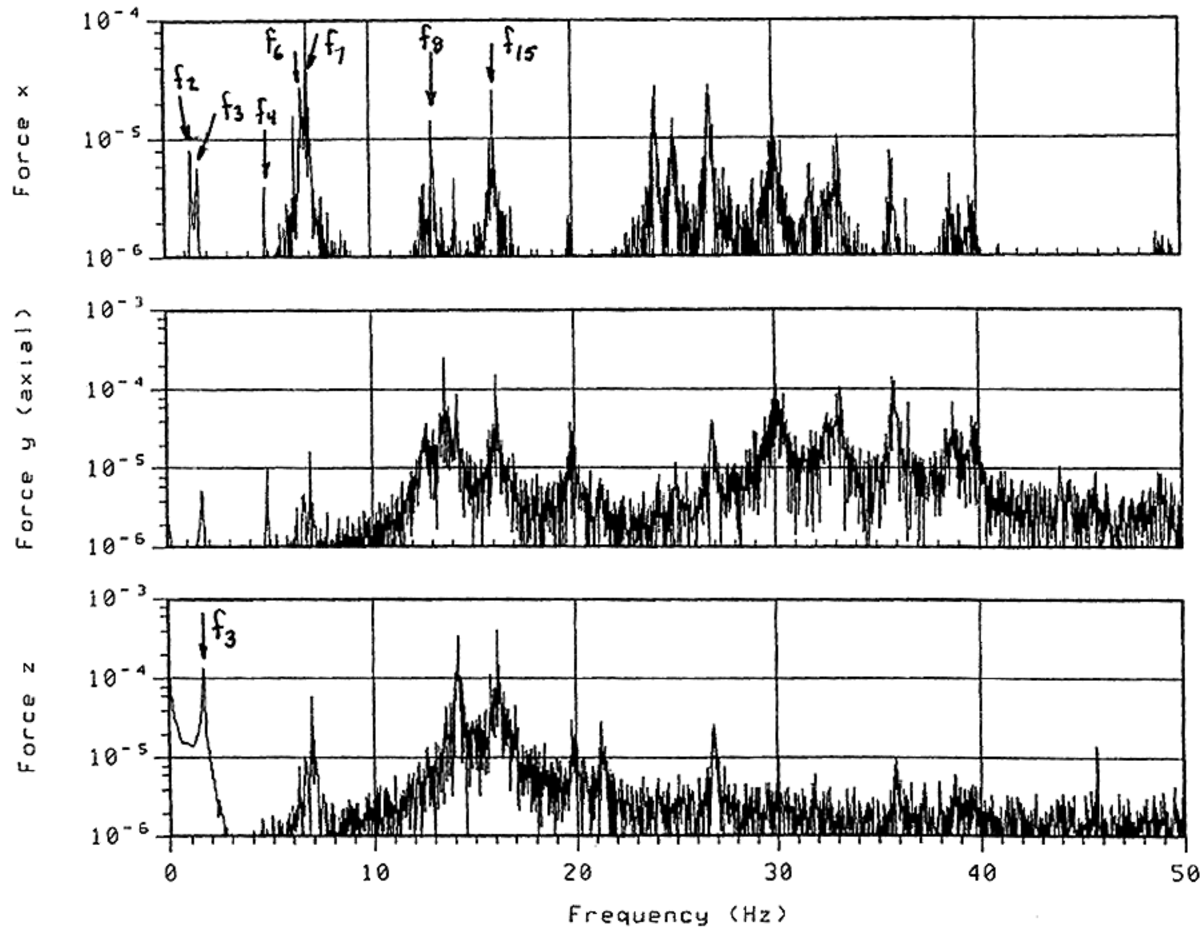
Sample of Results - Motion of a Point on the Solar Array



Thermally Induced SA3 Dynamics When Entering Sunlight

SWALES AEROSPACE

Sample of Results - Spectrum of the Interface Forces



Summary

- Thermal jitter analysis requires 3 diverse groups to work together in a 4 step process:

    1. Thermal - Development of the temperature transient
    2. Finite Element - Application of the temperatures onto the NASTRAN FEM
    3. Dynamics - Computation of open loop interface forces (and/or generalized forces)
    4. Controls - Application of forces to the system for control interaction

- Each step is clear, understandable and easy to do

- A test to confirm the results is recommended even though the small motions will be a challenge to measure